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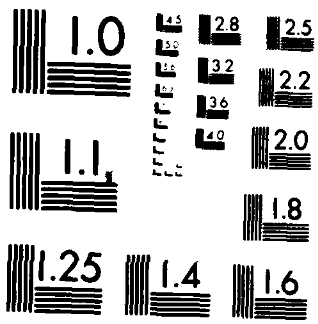
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FOREIGN TECHNOLOGY DIVISION

STEAM TURBINE AS UNIPOLAR GENERATOR

by

Ye.G. Oleynikov

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EDITED TRANSLATION

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Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*<u>ye</u> initially, after vowels, and after ъ, ь; <u>e</u> elsewhere.
When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

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STEAM TURBINE AS UNIPOLAR GENERATOR

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Ye. G. Oleynikov, Khar'nov

As early as the prewar years cases of magnetization during operation of low-powered (to 22 MW) steam turbines were observed [1].

In the last few years in the Soviet practice of operating several kinds of high-powered turbines at GRES [State Regional Electrical Power Plant] cases of noticeable magnetization [2, 3] have also been documented. Analogous cases of turbine magnetization in the operation of turbogenerators were also observed abroad [4].

Turbine magnetization results in a number of disturbances which reduce the operating reliability of the turbine assembly as a whole. The most characteristic and important such disturbances include:

1. Accumulation in the passage portion of the turbine of ferromagnetic particles from the boiler and the high-pressure lines.

2. Difficulty in removing the upper halves of the cylinders.

3. Current damage to bearings and seals.

4. Breakdowns in the system which monitors the thermomechanical movement of steam turbine elements - the axial shift of the rotor, expansion of the rotor relative to the turbine housing, curvature of the rotor shaft, etc.

5. Change in the vibration state of the turbine assembly.

6. Current damage in the regulating system, etc. Significant currents (several thousands of amperes) flowing from the shaft to the turbine housing may be merely the result of the unipolar induction phenomenon [5]. As experience in the use of steam turbines has shown us, their magnetization is usually caused during breakdowns associated with bending of the rotor shaft and the simultaneous catching of the rotor shaft on the turbine housing.

Recently several articles have appeared containing various proposals concerning the nature and mechanism of steam turbine magnetization [2, 4, 5]. In [6] it is reported that the German Society of Engineers and Electricians is patenting a method for demagnetization of steam turbines during operation. From this we draw the important conclusion that unmonitored and uncontrolled magnetic fields, particularly in turbines of high unit power, require immediate attention and serious study.

According to the data [2], turbine assemblies are magnetized by the current which travels along the connection between the poles in the excitation winding of the rotor of a synchronous generator. Taking into account the fact that the main magnetization criterion of the turbine is unipolar voltage measured along the shaft line of the turbine assembly, experimental studies conducted on a number of GRES and TETs [thermoelectric power plant], as well as on factory test stands, showed voltages of approximately the same order [3,7].

Actually, in the given case we are speaking of unipolar voltages, i.e., direct voltages. Alternating voltages may be observed in portions of the turbine between the low-pressure cylinder and the generator as a result of stray currents on the frontal portions and the presence of equalizing currents in the zero line between the synchronous generator and the transformer [8].

In [4] the self-excitation of the turbine as a unipolar generator is explained by the presence of an exciting magnetic current in the

end portion of the turbine shaft. This particular case was reproduced on a special experimental unit. Under actual conditions magnetization of the turbine can be circular, longitudinal, end, ect.

In [6] magnetization is believe to be caused primarily by the generator, although residual magnetization of individual parts in turbine units is not ruled out.

The results obtained from many experimental studies conducted by the author of the article on GRES and TETs, as well as the reports delivered by specialists in the field of unipolar electrical machines and physics at the First All-Union Conference of Higher Educational Institutes on Unipolar Electrical Machines [5] led to the conclusion that when three conditions were satisfied the turbine operates in a primarily cylindrical type of unipolar generator mode. These conditions are:

1. Hight peripheral speeds.
2. The presence of simultaneous bilateral contact (catching) between the rotor and turbine housing.
3. Magnetization at the beginning.

In the turbine the first condition is always met, while the second condition is usually met in breakdowns involving bending of the rotor shaft. Analysis of these breakdowns confirms the fact that cases of magnetization of the individual parts and turbine units are frequently observed. It is in these zones between the two contact points that significant induction, caused by high currents flowing between the shaft and the turbine housing, occur.

Figure 1 shows the distribution of induction on the periphery of the separation along the axis of a 150 MW turbine. The upper halves of the turbine cylinders are in this case lifted several centimeters [4]. The currents which flow over the contour between the rotor shaft and the housing are calculated by the law of total current. Magnetization was caused by damage to the main centrifical oil pump. Within a short time the pump shaft, 41 cm in diameter and connected by a worm gear to the high-pressure turbine shaft, was broken in the same place.

The three bearings of the pump and the regulating stage between the high-pressure cylinder and the pump made contact with low transient resistance between the shaft and the turbine housing. The second contacts, and also the contact with low transient resistance, judging from the data on distribution of magnetic induction along the turbine axis (see Fig. 1), are the result of the catching of the rotor on the housing of the intermediate-pressure cylinder. Toward the generator induction decreases to almost zero. The result of this damage was the development of significant currents, which together with the increased friction led to heating and wear of the pump shaft. In addition to this a significant current flowed through the upper portion of the bearings in the high-pressure cylinder. Signs of current (melting and heat discoloration) were revealed on the pump coupling flange, on the coupling teeth, and elsewhere.

The current in the shaft produced intense circular magetization of the high-pressure and the intermediate-pressure cylinders. Measurements revealed inductions above 0.4 T.

Such an induction distribution pattern, observed on K-200-130 blocks, is shown in Fig. 2.

The list of such examples of turbine magnetization could go on. The examples which we have mentioned are convincing evidence that magnetization of powerful steam turbines requires serious attention. There should be no unmonitored nor uncontrolled magnetic fields in turbines.

As for the third condition - existing magnetization - it has been thoroughly discussed in [3, 7]. It is necessary, however, to dwell in more detail on the possibility of magnetization of steam turbine parts during their heat treatment. As an example let us look at the heat regimes during heat treatment of a high-pressure cylinder made of steel EI-41 of the K-300-240 turbine.

The Curie point of this steel appears at a temperature of +770°-780°C. Ingot temperature is +750°C; sitting temperature +800°C;

forging at a temperature of +850-960°C (7 extractions); isometric annealing at a temperature of +980°C - 6 hours and at a temperature of +720°C = 26 hours; normalization at +1050°C, oil quenching at +1000°C, and tempering at +600° to + 300°C. Thus, during heat treatment and repeated forging a transition is observed through the Curie point, which may lead to weak magnetic fields and to noticeable magnetization of the rotor.

The author of this article presented a report [5] on the phenomenon of unipolarinduction in the work of a turbine in the unipolar generator mode at the First Scientific-Technical Conference, which was devoted to unipolar electrical machines. Upon this occasion the well known physicist and academician of the Siberian Branch of the AS USSR, L. V. Kerenskiy, confirmed the main points in the report, particularly magnetization of ferromagnetic parts in weak magnetic fields upon passing the Curie point.

From the above it appears that one reason for the original magnetization of turbine parts during their manufacture may be heat treatment. In addition, we believe that the original magnetization in the case of bilateral simultaneous catching in the turbine may be the result of the difference in the thermal emf between the catching points, i.e., the current and magnetization caused by this effect may also be the reason for the turbine working as a unipolar generator.

On the basis of the above one might conclude that a steam turbine in the presence of bilateral simultaneous contact and an existing magnetic field during the operating process may work in the mode of a unipolar generator.

Summarized below are the physical principles of the working of a unipolar generator of the cylindrical type as it applies to a steam turbine.

The pioneering study in the field of unipolar electrical machines is the monograph by A. I. Bertinov, B. L. Aliyevskiy, and S. R. Troyitskiy [9]. Thus all of the main arguments, terminology, formulas,

etc. for the case of a turbine working in a unipolar generator mode go back to this study.

Figure 3 shows a schematic representation of the unipolar generator of the cylindrical type. The rotor shaft of the turbine is a cylindrical armature of a unipolar generator and rotates in a magnetic field of constant polarity. Induced emf can be expressed as:

$$e = -\frac{d\Psi}{dt} = -W\frac{d\Phi}{dt}. \qquad (1)$$

In the general case the magnetic flux Φ, bounded by a circuit formed by the elementary armature conductor and the external circuit, represents a function of time t and the rotation angle of the rotor (armature) φ. The external circuit (for our case) is the turbine housing in the presence of bilateral contact. In a steady regime in the unipolar generator the current is constant in time, and thus

$$\frac{d\Phi}{dt} = \frac{\partial\Phi}{\partial t} + \frac{\partial\Phi}{dt}\cdot\frac{d\varphi}{dt} = \omega\frac{\partial\Phi}{\partial\varphi}, \qquad (2)$$

where

$$\omega = \frac{d\varphi}{dt}.$$

If we consider the fact that the turbine rotor has a number of armature coils W = 1, then by omitting the minus sign (1), we get

$$e = \omega\frac{\partial\Phi}{d\varphi}. \qquad (3)$$

For a cylindrical machine

$$\Phi_{\kappa} = \int_0^{2\pi} B_{\delta}(\varphi)\frac{Dl}{2}\cdot d\varphi. \qquad (4)$$

where B_δ is induction in the air gap; l - the length of the armature between contact points and D - the diameter of the armature.

Assuming the induction in the gap between the armature and the turbine housing to be constant, i.e., $B_\delta(\varphi) = B_\delta = \text{const}$, we get

$$e_u = \frac{\omega}{2} B_\delta Dl = \pi n B_\delta Dl = B_\delta lv = \Phi_u n. \tag{5}$$

In the case of bilateral contact the current which flows through the rotor-turbine housing circuit equals

$$I = \frac{e_u}{R_p + R_k} = \frac{U}{R_{nr}}, \tag{6}$$

where $R_p + R_k$ is the resistance of the contour between the contact points.

The value of this resistance according to the measurements taken in [4] constitutes fractions of a million and microohms in certain cases. Hence it appears that experimentally obtained emf along the shaft line of a turbine assembly on the order of one hundred or more millivolts may in the case of bilateral contact cause a rotor-housing circuit of significant current to develop.

This generator has a unique armature reaction. The magnetic field of the armature reaction is tangential and, together with the main, radial magnetic field, creates a resultant magnetic field with spiralling induction line, i.e., excitation occurs from within the turbine rotor. The armature reaction may be longitudinal and transverse, depending on whether the contact bearing bilateral catching is symmetrical or nonsymmetrical.

The technological process of manufacturing the parts and steam turbine assemblies may be the reas n for the development of dangerous magnetic fields. It is fc .hi: .eason that, together with our coworkers at the magnetic laooratory of the Central Plant Laboratory

of the S. M. Kirov Turbine Plant, we selected special equipment and developed a program by which the main turbine parts (bearings, rotors, housings, etc.) from the billet right up to the final finishing, would be tested for magnetization prior to assembly.

The purpose of the experimental studies was to determine the technological process in which magnetization of parts occurs in order to prevent these parts from going into the assembled turbine without preliminary demagnetization.

A program has also been outlined for measuring the magnetization of parts and turbine assemblies during operation at GRES and TETs.

The results of this research should aid us in developing measures for demagnetization of turbines during operation.

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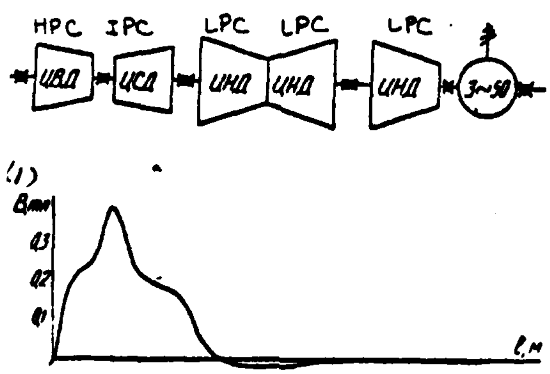
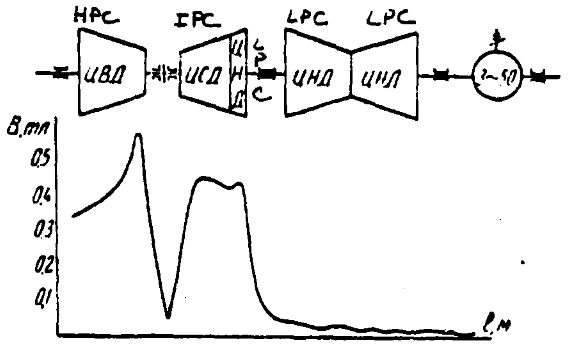


Fig. 1. Distribution of induction on separation periphery of turbine housing along axis of 150 MW turbine assembly.

KEY: (1) V, T.



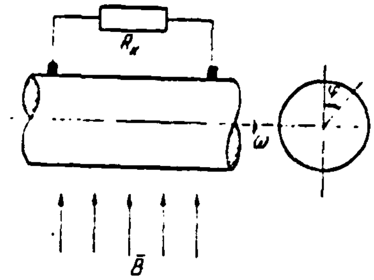


Fig. 2.

Fig. 3.

Fig. 2. Distribution of induction on separation periphery of turbine housing along axis of K-200-130 turbine assembly.

Fig. 3. Induction of emf in unipolar generator of cylindrical type.

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